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CALCULATING TEMPERATURE OF TURBINE BLADES WITH EFFUSION COOLING--ETC(U)
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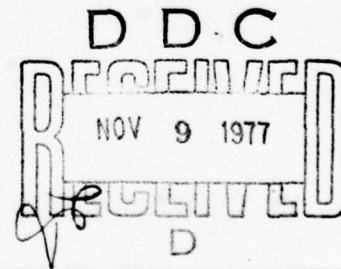
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by

V. I. Lokay, S. G. Dezider'yev



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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	<i>А а</i>	A, a	Р р	<i>Р р</i>	R, r
Б б	<i>Б б</i>	B, b	С с	<i>С с</i>	S, s
В в	<i>В в</i>	V, v	Т т	<i>Т т</i>	T, t
Г г	<i>Г г</i>	G, g	У у	<i>У у</i>	U, u
Д д	<i>Д д</i>	D, d	Ф ф	<i>Ф ф</i>	F, f
Е е	<i>Е е</i>	Ye, ye; E, e*	Х х	<i>Х х</i>	Kh, kh
Ж ж	<i>Ж ж</i>	Zh, zh	Ц ц	<i>Ц ц</i>	Ts, ts
З з	<i>З з</i>	Z, z	Ч ч	<i>Ч ч</i>	Ch, ch
И и	<i>И и</i>	I, i	Ш ш	<i>Ш ш</i>	Sh, sh
Й й	<i>Й й</i>	Y, y	Щ щ	<i>Щ щ</i>	Shch, shch
К к	<i>К к</i>	K, k	Ъ ъ	<i>Ъ ъ</i>	"
Л л	<i>Л л</i>	L, l	Ы ы	<i>Ы ы</i>	Y, y
М м	<i>М м</i>	M, m	Ь ь	<i>Ь ь</i>	'
Н н	<i>Н н</i>	N, n	Э э	<i>Э э</i>	E, e
О о	<i>О о</i>	O, o	Ю ю	<i>Ю ю</i>	Yu, yu
П п	<i>П п</i>	P, p	Я я	<i>Я я</i>	Ya, ya

*ye initially, after vowels, and after Ъ, ь; e elsewhere.
 When written as ë in Russian, transliterate as yë or ë.
 The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	A	α	α	Nu	N	ν
Beta	B	β		Xi	Ξ	ξ
Gamma	Γ	γ		Omicron	Ο	ο
Delta	Δ	δ		Pi	Π	π
Epsilon	E	ε	ε	Rho	Ρ	ρ ϑ
Zeta	Z	ζ		Sigma	Σ	σ ς
Eta	H	η		Tau	Τ	τ
Theta	Θ	θ	θ	Upsilon	Υ	υ
Iota	I	ι		Phi	Φ	φ φ
Kappa	K	κ	κ	Chi	Χ	χ
Lambda	Λ	λ		Psi	Ψ	ψ
Mu	M	μ		Omega	Ω	ω

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
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sin	sin
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cos	cos
-----	-----

tg	tan
----	-----

ctg	cot
-----	-----

sec	sec
-----	-----

cosec	csc
-------	-----

sh	sinh
----	------

ch	cosh
----	------

th	tanh
----	------

cth	coth
-----	------

sch	sech
-----	------

csch	csch
------	------

arc sin	\sin^{-1}
---------	-------------

arc cos	\cos^{-1}
---------	-------------

arc tg	\tan^{-1}
--------	-------------

arc ctg	\cot^{-1}
---------	-------------

arc sec	\sec^{-1}
---------	-------------

arc cosec	\csc^{-1}
-----------	-------------

arc sh	\sinh^{-1}
--------	--------------

arc ch	\cosh^{-1}
--------	--------------

arc th	\tanh^{-1}
--------	--------------

arc cth	\coth^{-1}
---------	--------------

arc sch	sech^{-1}
---------	----------------------------

arc csch	csch^{-1}
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rot	curl
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lg	log
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CALCULATING TEMPERATURE OF TURBINE BLADES WITH EFFUSION COOLING

V. I. Lokay, S. G. Dezider'yev

Calculations show that when the parameters of the working fluid are sufficiently high, internal convective cooling of turbine blades is ineffective. The temperature of the outer surface of the blade remains inadmissibly high and the temperature gradient in the sleeve is too great.

It is for this reason that the so called effusion method of cooling the flow part [3] has been the subject of ever increasing attention. The outer wall of the turbine blade (sleeve) is made in this case of a permeable sheet material.

The low relative curvature of the convex and concave parts of the blade profile make it possible to analyze them approximately as plates. The inlet and outlet edges can be regarded as the walls of cylinders with a well known approximation. Presented in the present work are the analytical relationships for calculating the distribution of temperatures over the thickness of porous blade walls under boundary conditions of the third type. In contrast to [1] and [2], where the calculation is made under the assumption that the temperatures of the coolant and the walls are equal, this limitation has been removed in the present article, increasing its accuracy [4].

Temperature Distribution with Respect to Wall Thickness on Convex and Concave Portions of the Profile (Flat Wall)

The calculation scheme is shown in Fig. 1. Under stationary conditions for a wall element of length dx

$$q_{x+dx} - q_x - dq_0 = 0, \quad (1)$$

where

$$q_x = \lambda \bar{f}_{\text{ck}} \left(\frac{dt}{dx} \right)_x; \quad (2)$$

$$q_{x+dx} = - \lambda \bar{f}_{\text{ck}} \left(\frac{dt}{dx} \right)_{x+dx}; \quad (3)$$

$$dq_0 = \alpha_v (t - t_0)_x \cdot dx. \quad (4)$$

Here $\bar{f}_{\text{ck}} = \frac{f_{\text{ck}}}{f}$; f - the area of the space surface of the wall; f_{ck} - area of cross section of wall frame normal to the stream of fluid; λ, α_v - heat conductivity of wall and volumetric heat exchange coefficient averaged over thickness; t, t_0 - temperature of wall and coolant in studied sections.

The porosity of the material is usually characterized by the quantity

$$\Pi = \frac{\rho_c - \rho_n}{\rho_c} = 1 - \bar{\rho}, \quad (5)$$

where ρ_c, ρ_n is the density of the material without pores (solid) and with pores, respectively.

When the structure of the porous material is homogeneous, on the basis of (5) we easily come to the conclusion that numerically

$$f_{\text{ck}} = 1 - \Pi = \bar{\rho}. \quad (6)$$

Considering equality (6), from expression (1) we find

$$\lambda \rho \frac{d^2 t}{dx^2} - \alpha_v (t - t_0) = 0. \quad (7)$$

On the other hand, according to the equation of enthalpies

$$dq_0 = G_0 C_{p0} dt_0. \quad (8)$$

where G_0 is the mass flow rate of the coolant inside the plate ($f = 1$ m²); C_{p0} - the average isobaric heat capacity of the coolant with respect to wall thickness.

By comparing (4) and (8), we find

$$G_0 C_{p0} dt_0 = \alpha_v (t - t_0) dx \quad (9)$$

or

$$\frac{dt_0}{dx} = \frac{\alpha_v}{G_0 C_{p0}}. \quad (10)$$

By jointly solving (7) and (10), after certain simple mathematical transformations and a shift to dimensionless variables

$\bar{x} = \frac{x}{\delta}$ and $\theta = \frac{t}{t_f}$, we finally get

$$\frac{d^3\theta}{d\bar{x}^3} + k_1 \frac{d^2\theta}{d\bar{x}^2} - k_2 \frac{d\theta}{d\bar{x}} = 0. \quad (11)$$

Here $k_1 = \frac{a_v \delta}{G_0 C_{p0}}$; $k_2 = \frac{a_v \delta^2}{\lambda \rho}$.

The solution to equation (11) takes the form of

$$\theta = C_1 e^{a_1 \bar{x}} + C_2 e^{a_2 \bar{x}} + C_3 e^{a_3 \bar{x}}, \quad (12)$$

where a_1 , a_2 , and a_3 are the roots of the characteristic equation

$$a^3 + k_1 a^2 - k_2 a = 0. \quad (13)$$

From (13) it follows directly that $a_1 = 0$,

$$a_{2,3} = -\frac{k_1}{2} \pm \sqrt{\frac{k_1^2}{4} + k_2}.$$

Thus, we finally get

$$\theta = C_1 + C_2 e^{a_2 \bar{x}} + C_3 e^{a_3 \bar{x}}. \quad (14)$$

Integration constants C_1 , C_2 , and C_3 are found from the boundary conditions of the 3rd type (symbols shown in Fig. 1):

when $\bar{x} = 0$

$$\alpha_6 (\theta' - \theta_{0\infty}) = \frac{\lambda_p}{\delta} \left(\frac{d\theta}{d\bar{x}} \right)_{\bar{x}=0}, \quad (15)$$

where

$$\theta' = \frac{t'}{t_r^*}; \quad \theta_{0\infty} = \frac{t_{0\infty}}{t_r^*};$$

when $\bar{x} = 1$

$$\alpha_r (1 - \theta'') = \frac{\lambda_p}{\delta} \left(\frac{d\theta}{d\bar{x}} \right)_{\bar{x}=1}, \quad (16)$$

where $\theta'' = \frac{t''}{t_r^*}$;

when $\bar{x} = 0$, from equation (7) in dimensionless form

$$\left(\frac{d^2\theta}{d\bar{x}^2} \right)_{\bar{x}=0} - \frac{\alpha_p \lambda_p^2}{\lambda_p} (\theta' - \theta_0) = 0, \quad (17)$$

where $\theta_0 = \frac{t_0'}{t_r^*}$.

Thus, we find

$$C_1 = \frac{\Delta C_1}{\Delta}; \quad C_2 = \frac{\Delta C_2}{\Delta}; \quad C_3 = \frac{\Delta C_3}{\Delta},$$

where

$$\Delta C_1 = \begin{vmatrix} \theta_{0\infty} (1 - b_0 a_2) & (1 - b_0 a_3) \\ \theta_r^* [(1 + b_r a_2) e^{a_2}] & [(1 + a_3 b_r) e^{a_3}] \\ \theta_\infty \left(1 - a_2^2 \frac{b_r}{d}\right) & \left(1 - a_3^2 \frac{b_r}{d}\right) \end{vmatrix};$$

$$\Delta C_2 = \begin{vmatrix} 1 & \theta_{0\infty} & (1 - b_0 a_3) \\ 1 & \theta_r^* & [(1 + a_3 b_r) e^{a_3}] \\ 1 & \theta_{0\infty} & \left(1 - a_3^2 \frac{b_r}{d}\right) \end{vmatrix};$$

$$\Delta C_y = \begin{vmatrix} 1 & (1 - b_0 a_1) & \theta_{0\infty} \\ 1 & [(1 + a_2 b_r) e^{a_2}] & \theta_r^* \\ 1 & \left(1 - a_2^2 \frac{b_v}{d}\right) & \theta_{v\infty} \end{vmatrix};$$

$$\Delta = \begin{vmatrix} 1 & (1 - b_0 a_1) & (1 - b_0 a_3) \\ 1 & |(1 + b_r a_2) e^{a_2}| & |(1 + b_r a_3) \cdot e^{a_3}| \\ 1 & \left(1 - a_2^2 \frac{b_v}{d}\right) & \left(1 - a_3^2 \frac{b_v}{d}\right) \end{vmatrix}.$$

Here, for the sake of brevity we will designate

$$\frac{\lambda_p}{a_0 \delta} = b_0; \quad \frac{\lambda_p}{a_r \delta} = b_r; \quad \frac{\lambda_p}{a_v \delta^2} = b_v; \quad 1 - \frac{a_0}{G_0 C_{p_0}} = d.$$

As an example Fig. 2 shows the temperature distribution with respect to wall thickness, calculated by the described method (curve 1). Here point 2 marks the temperature of the outer surface in the case of convective coolant, calculated for the same starting data and flow rate of the coolant. There is a sharp temperature in the case of porous cooling. The dashed line (curve 3) shows the behavior of the temperature in the wall, calculated according to the method of [2] with noticeable temperature distortion. Analysis shows that calculation error here increases as the thermal head between the gas and the coolant increases and also when α_v , δ and λ_{cr} decreases. This increase may reach 10-20% [5].

Temperature Distribution with Respect to Wall Thickness in Vicinity

of Blade Edges (Cylindrical Wall)

The calculation scheme and the main symbols are shown in Fig. 3. Under the same assumption used earlier from the equation of thermal balance

$$q_{r+dr} - q_r - dq_0 = 0 \quad (18)$$

we can get

$$\frac{d^3\theta}{dr^3} + \xi(\bar{r}) \frac{d^2\theta}{dr^2} + \zeta(\bar{r}) \frac{d\theta}{dr} = 0, \quad (19)$$

Here

$$\begin{aligned} \bar{r} &= \frac{r}{r_r}; \quad \theta = \frac{t}{t_r^*}; \quad \xi(\bar{r}) = k_{v1} + \frac{1}{\bar{r}}; \\ \zeta(\bar{r}) &= \frac{k_{v1}}{\bar{r}} - \frac{1}{\bar{r}^2} - k_{v1}, \end{aligned}$$

where for brevity we designate

$$\frac{\alpha_v r_r^2}{\lambda \rho} = k_{v1}, \quad \frac{\alpha_v r_r}{G_0 C p_0} = k_{v1}.$$

Equation (19) determine the temperature distribution in a cylindrical wall cooled by the effusion method.

Received 28 June 1967

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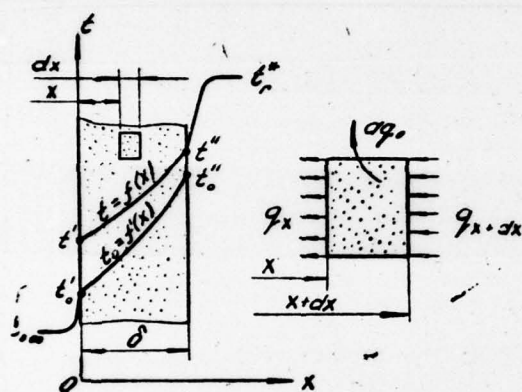


Fig. 1.

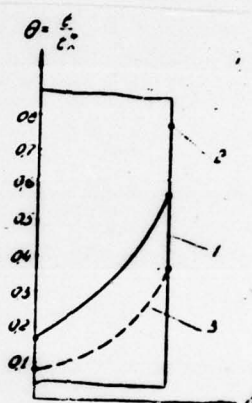


Fig. 2.

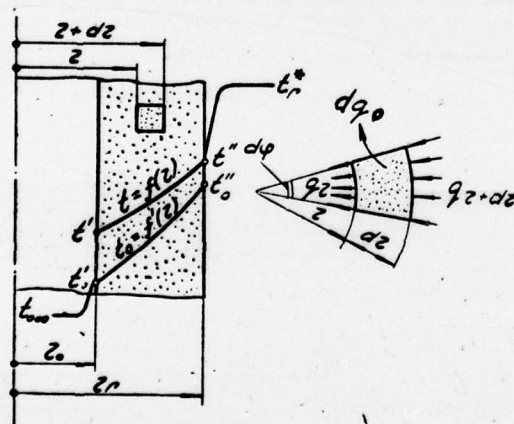


Fig. 3.

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